

Experimental Analysis and Control of a Wind-Generator System through a DC-DC Boost Converter for Extremum Seeking

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Abstract-The advancement in technology has significantly improved the living standard, having a direct impact on the quality of life, at the cost of ever-increasing energy demand. Renewable energy resources such as the Wind Energy Conversion System (WECS) provide variable power generation. The current paper presents the results of the experimental analysis on the control of the wind-generator system based on SCIG through a dc/dc boost converter for extremum power-seeking. Since the Squirrel Cage Induction Generator (SCIG) is widely used in wind industries for power generation, their performance will be compared. The proposed system can operate either on a variable or at a nearly constant speed, with higher load capacity, while its power consumption is comparatively lower. The research will enhance the wind power at different wind speeds, to acquire the extremum power point tracking system from the wind power energy system by using two different machines.

Keywords-wind power energy; extremum power tracker; dc/dc converters; SCIG

I. INTRODUCTION

Most countries face problems when using conventional sources such as coal, natural gas, and oil for the generation of energy, due to the imminent depletion of non-renewable resources and ecological problems. Due to environmental problems, such as the global warming and the greenhouse effect, there is an increasing attention on renewable sources of energy. Wind power energy is an obtainable renewable energy source, it is clean, and practically infinite [1] and is the most prominent source of energy for power generation [2]. Several studies have been carried out to regulate the way extremum

wind power can be taken from the wind energy power generation system [3]. In Figure 1, we can see the increasing trend of the year-wise global cumulative capacity (GW) [3].

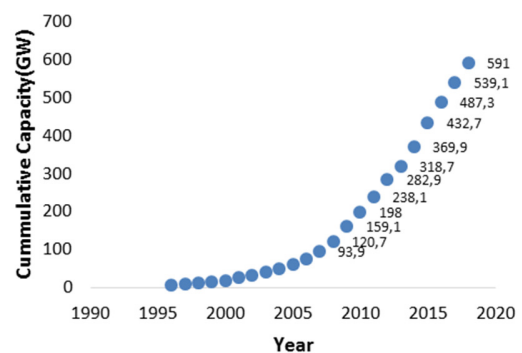


Fig. 1. Globally wind power cumulative capacity (data taken from [3]).

The energy sector of Pakistan has improved significantly in 2020, but still faces a shortage of 6GW [4]. Due to the energy deficit, the industrialized and commercial segments utilize diesel generators, while residential consumers are using Uninterrupted Power Supply (UPS) units which increase the operating cost [5]. The Pakistan Meteorological Department (PMD) has carried out a detailed study of the wind energy potential of the coastal regions of Pakistan [6], allowing us to recognize possible exploitable windy regions [7], e.g. the shore regions of Sindh have a better potential for wind power energy than the shore regions of Baluchistan [8]. The candidate regions occupy 9700km² in Sindh. A potential capacity of this

cumulative wind power energy in the mentioned region is around 43,000MW [9]. By considering the limitations of the utilization of the region, it is estimated that the exploitable potential of electric power generation in this area is approximately 11,000MW [10].

This research study uses variable speed for wind power systems which has numerous benefits associated with constant speed wind power energy scheme, such as producing extremum wind power energy from the network and developing small mechanical stress by improving the efficiency and quality of the energy. The current paper presents the results of experimental analysis on the control of a wind generator system based on Squirrel-Cage Induction Generators (SCIGs), through a dc/dc converter for extreme energy seeking. The SCIGs are generators of frequent use at the industrial level, they are cheap, and can operate at different, constant or variable, speeds, with great load capacity, and their energy consumption is comparatively low. The objective is the acquisition of extremum wind power at different wind speeds and the implementation of the dc/dc boost converter for extremum seeking control.

II. THE PROPOSED EXPERIMENTAL SETUP

The block diagram of Figure 2 shows the SCIG, which is driven through a prime mover. At the coupling of the prime mover and the SCIG, the rpm of the generator is measured by a tachometer.

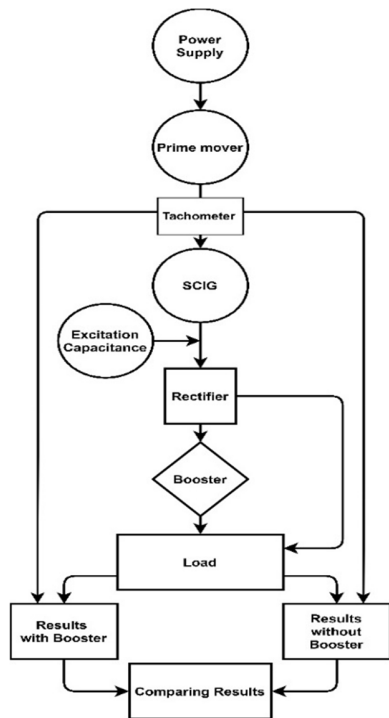


Fig. 2. Flowchart of the proposed setup.

The excitation of SCIG is controlled by the excitation capacitance and feeds the rectifier. After that the observation of generated power with and without booster at variable wind speed is compared using dummy load.

III. WIND GENERATION MODELING CHARACTERISTIC EQUATIONS

The output power from the wind turbine is expressed as [11]:

$$P_W = 0.5\rho\pi C_p(\lambda, \beta)R^2V_\omega^3 \quad (1)$$

where $\rho = 1.25kg/m^3$ is the density of the wind, R represents the turbine blade length, V_ω is the speed of wind, $C_p = 0.3$ to 0.5 is the power coefficient, the pitch angle is represented by β (supposing zero degrees at Zone-II), and λ is the tip speed ration described as ([12]):

$$\lambda = \frac{\omega R}{V_\omega} \quad (2)$$

where ω is the rotor speed of wind generator in rad/sec. The relationship between turbine power and wind power is defined as [13]:

$$P_t = T_t \omega_t = C_p(\lambda, \beta)P_W \quad (3)$$

$$C_p = (0.73)151 \frac{1}{R\omega_t} V_\omega - 13.645e^{\left(\frac{V_\omega}{R\omega_t} - 0.003\right)^{-1}} \quad (4)$$

The output power of the wind generator system is driven from (1)-(4) and defined by the wind speed, as calculated from [14]:

$$P_t = 55.155\rho A \frac{V_\omega}{R\omega_t} - 0.09e^{\left(\frac{V_\omega}{R\omega_t} - 0.003\right)^{-1}} \quad (5)$$

The power of the wind turbine system at the speed of the wind turbine is shown in Figure 3 by using (5). It is clearly visible that the power of wind turbine changes with respect to the speed of wind turbine which depends on wind speed. The graph shows that the 3rd order curve gives maximum power generated by a wind turbine at different wind speeds [15].

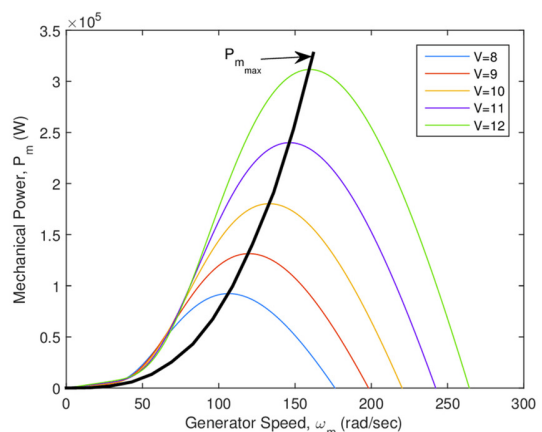


Fig. 3. Wind turbine power curve.

IV. EXPERIMENTAL MODEL DESIGN

The experimental model for the wind generation system is shown in Figure 4. The wind energy conversion system consists of a 3-phase sinusoidal voltage which is inverted to dc voltage through a rectifier. Our main objective is to generate and control the extremum power from the wind generation

system through dc-dc converters by changing their duty cycle at the DC side. The experimental circuit diagram for the dc-dc boost converter is shown in Figure 5.

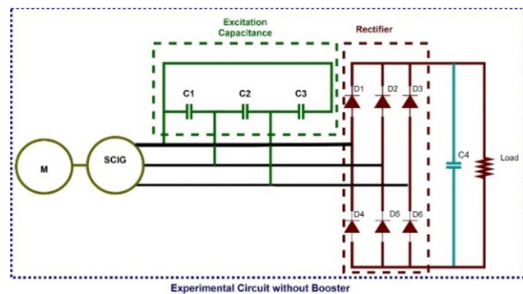


Fig. 4. Experimental circuit without booster.

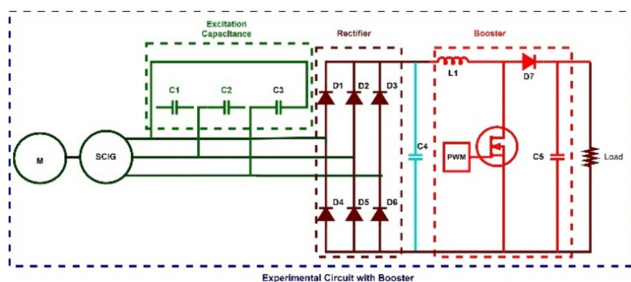


Fig. 5. Experimental circuit with booster.

V. EXPERIMENTAL SETUP

The Experimental model of Wind Energy Conversion System (WECS) requires a wind channel, which is normally assembled to generate controlled wind speed to run a wind energy conversion system. However, it is expensive and space challenging. A software simulator is simple but with many restrictions. The best way to use the characteristics of the wind turbine is by using an engine generator (MG) –set, in which the engine is functioned and controlled to re-produce the wind energy converter system scheme at variable wind speeds. Through a comprehensive study, the MG set was used as a prime mover for the WECS. The SCIG was used for power generation at variable wind speed. A permanent magnet DC machine was used as a wind turbine emulator to analyze the non-linear behavior of the wind turbine. In this experimental setup, the motor works at varying speed in order to examine the generated output power from the SCIG with and without DC-DC boost converters. Our main objective is to acquire the maximum wind power at different wind speeds, through the dc/dc boost converter for extremum power-seeking. The experimental models without and with the booster based on dc-dc boost converter are shown in Figures 6 and 7 respectively.

Initially, the wind energy power system was operated without DC-DC boost converters, connected to the rectified output of a SCIG to calculate output parameters such as voltage, current, and power under variable speed conditions. The resistive load was used as an imaginary load to take continuous power measurements for generator output analysis. To acquire extremum power, the modified output of the wind generator system was fed to the dc-dc booster, which consists

of a single MOSFET while the capacitor values calculated from primary to secondary are $470\mu\text{f}$, 450V , $680\mu\text{f}$, and 450V respectively. The rated value of the output inductor is 1.8mH , 2.5A , with a switching frequency of about 240kHz (Table I). The efficiency of the system's response to the proposed controller scheme based on boost converters impulse converter was confirmed by a different duty cycle.

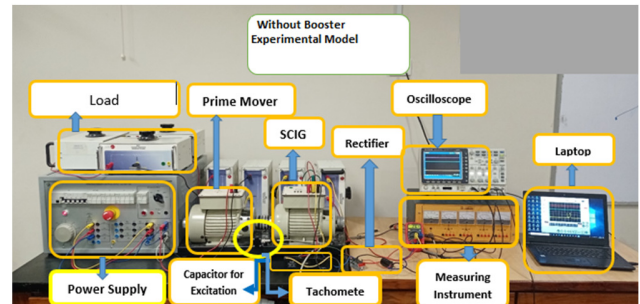


Fig. 6. Experimental model without booster.

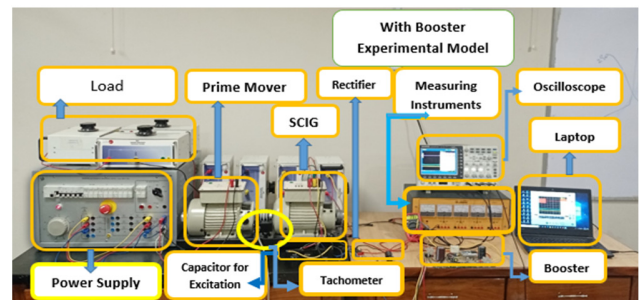


Fig. 7. Experimental model with booster.

VI. RESULTS AND DISCUSSION

The results were extracted at variable wind speed of the prime mover and different time intervals in order to analyze the wind turbine system output by using SCIG. The permanent magnet direct current machine was used as the prime mover. The SCIG was coupled with a wind turbine channel and was operating at variable wind speeds. In the experimental model of WECS, it is important to observe parameters like current, voltage, and power at varying wind speed. The without-booster scheme was applied to the wind generator system. The SCIG operated at variable wind speed and the generated power was measured at different time intervals. The speed (rpm) response with respect to time is shown in Figure 8, which shows that the speed of the generator increases with respect to time as the speed in rpm is increased: from 4 to 6s it gets from 400 to 600rpm and from 10 to 12s from 1000 to 1100rpm.

The main objective is to analyze the output power without a booster at different wind speeds to observe the power (W) vs speed (rpm). Figure 9 shows the speed vs power graph, in which the generation of wind power ranges from 600rpm to 1000rpm and reaches 105.9W when the speed of wind turbine reaches 1150rpm . Secondly, in the experimental model, the generated power was observed at variable wind speed with a booster applied to the wind generator system output. The SCIG

was operated at different wind speeds and its output power was measured at different time intervals. Our main objective was to analyze the output power with booster at different wind speeds. The extremum power was achieved by varying the duty cycle with the help of the PWM method, as a pulse feed to the gate of MOSFET used in dc-dc boost converters. Figure 10 shows the power with respect to turbine speed. The power generation was 105W at 1000rpm, and the generation increased to 144W at 1150rpm. The duty cycle and wind speed changed in order to extract the maximum power by varying the point of energy conversion. In this experimental setup, the duty cycle changed from 10% to 16.60% as shown in Figure 11.

TABLE I. EQUIPMENT DESCRIPTION

List of equipment	Descriptions and model no
Power supply	Power electronics universal supply model No:AEP-1/EV
Prime mover (DC-PMSG)	2500rpm, type EM-3330-1A 180V dc, 2.7A, 0.4KW, S/N:201
3-phase SCIG	0.3KW,1420/1670rpm type: EM-3330-3C 3-phase, 220V, 1.4A, 50/60Hz, S/N:201
Tachometer	Tachometer 20713 A
Excitation capacitors (cap)	15µf ±5% 350-400 VAC
3-phase rectifier	AQL5010-5A
Booster	Capacitor 1:470µf,450V Capacitor 2:680µf,450V Inductor:1.8mH 5A Diode:FR305 MOSFET
Measuring instruments	Oscilloscope, model:DL:10282
Digital oscilloscope	GW Instek GDS-2074
Laptop	PC: Toshiba

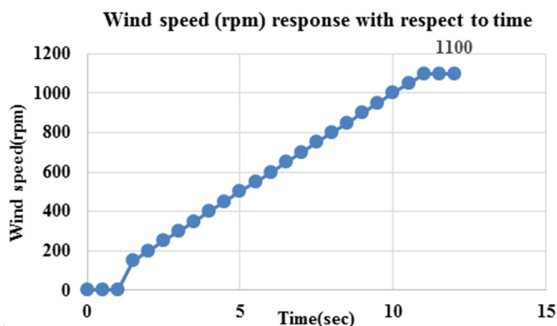


Fig. 8. Wind speed response with time.

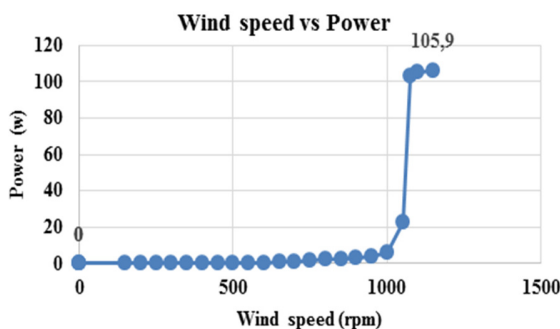


Fig. 9. Power response without booster at variable wind speed.

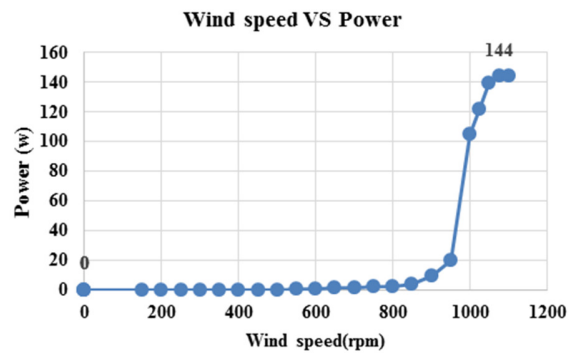


Fig. 10. Power response with booster at variable wind speed.

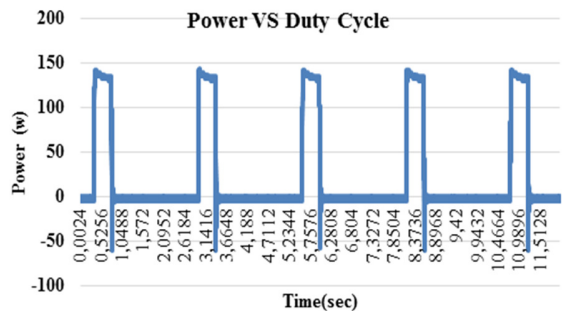


Fig. 11. Power response at varying duty cycle.

VII. WITHOUT VS WITH BOOSTER RESULT COMPARISON

The experimental results are summarized in Figure 12. The configuration without booster generated power from setup at different wind speed is 105.9W at 1100rpm but at the same time, the extraction of the maximum power by using the dc-dc booster is 144W at 1100rpm.

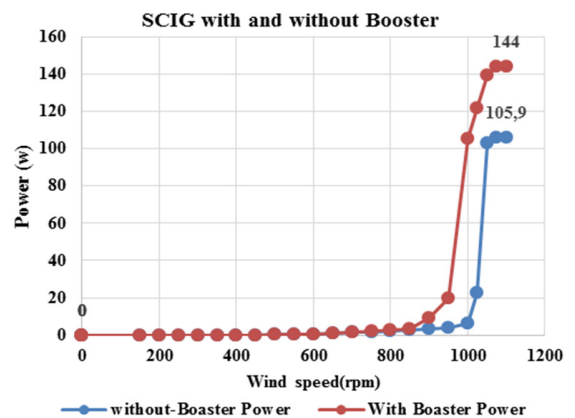


Fig. 12. Power response with and without booster at varying wind speed.

VIII. CONCLUSION

The current paper presents an experimental setup for a WECS based on SCIG through dc-dc converters for extremum power-seeking. The advantage of this model is that it generates the power at variable speed from the wind energy system, due to this the variable speed wind energy generator system faces

the least pressure on different varying factors like gear or shaft of the system. The dc-dc boost converters are independent of the speed of the wind. The proposed experimental model characterized the generated output power from the wind generator system. The dc-dc converters provide extremum power at the grid end by changing the duty cycle connected with the rectifier. The proposed experimental setup can be adjusted efficiently to the current wind energy system at varying speed, in the minimum wind speed area. The dc-dc converters provide maximum power at the end of the grid by changing the duty cycle connected to the rectifier.

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